THERMAL & FLUIDS
ANALYSIS WORKSHOP

GSFC · 2015

A Comparison of Geometric Discretization Methods

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Background

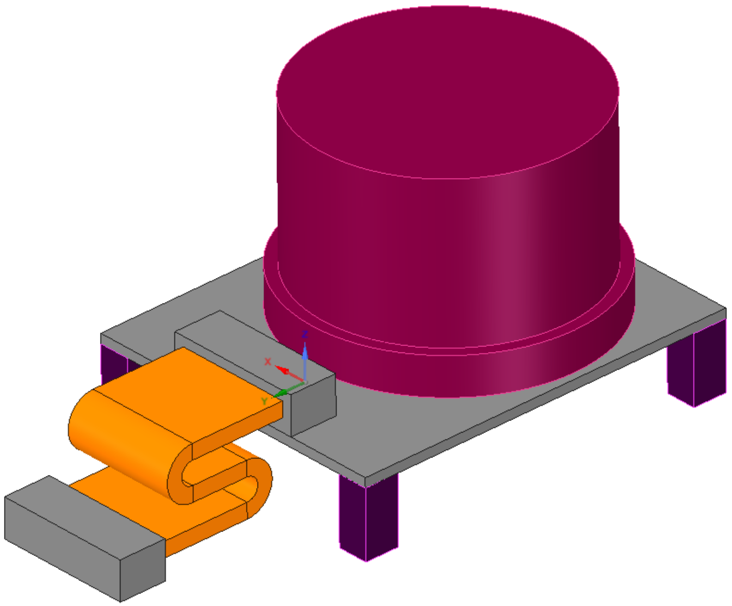
- Thermal analyses often require a system-level model
  - Quick evaluation of the overall system
  - Interactions between components
  - Boundary conditions for component-level models
- System-level models should
  - Adequately represent components
    - Accurate mass drives transient solution accuracy
    - Accurate area drives convection and radiation accuracy
  - Run quickly for evaluating design space or design changes
  - Correlate to test data
- This presentation will focus on discretization methods appropriate for system-level models
  - Compare models created with various discretization methods
  - Evaluate the strengths and weaknesses of each method

Discretization Methods

- Finite Difference
  - Geometry defined using geometric primitive shapes
- Flat Finite Elements
  - Structured or unstructured meshes define geometry shape
  - Curved geometry is faceted, *requiring many elements*
- Curved Elements
  - Curved geometry is *accurately represented using few elements*
  - Tessellated and exact options for radiation calculations
    - Tessellated subdivides curved surface elements using facets with area correction factors
    - Exact uses precise geometric representation

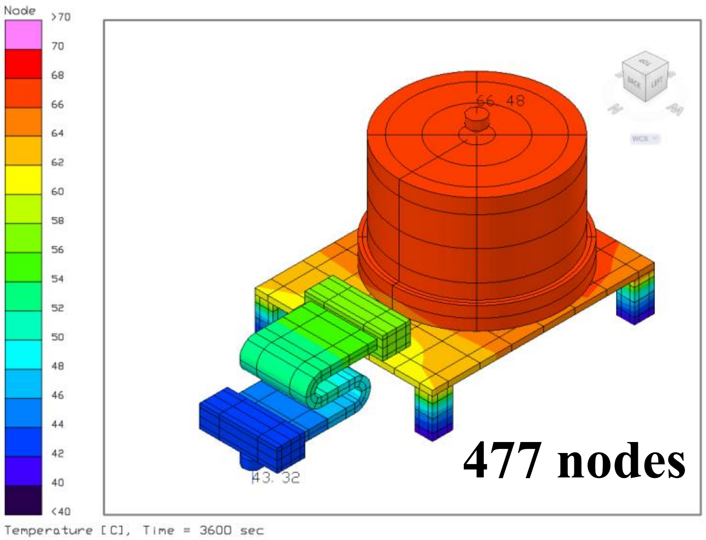
Conduction and Radiation Model

- Reaction wheel with thermal strap
- Conduction and radiation boundary conditions
- Radiation*
  - Minimum 10k rays per node
  - 1% statistical error
  - Maximum 1M rays per node
- Transient thermal solution

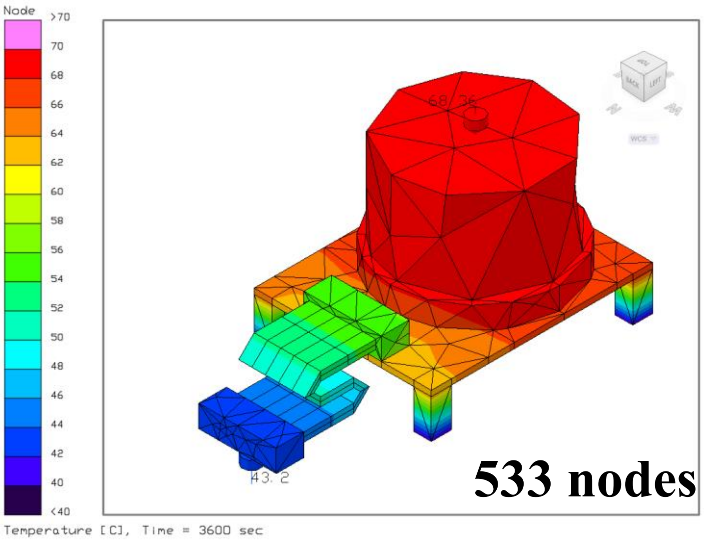


* Not typical values; purposefully over-resolved

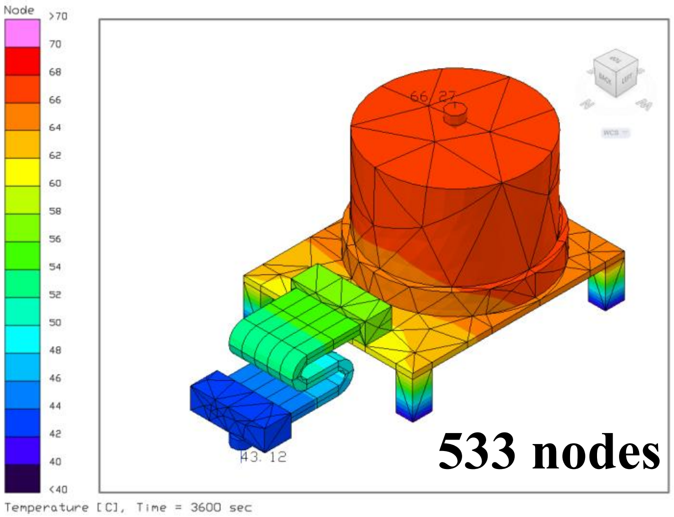
Reaction Wheel Models with ~500 Nodes



Finite Difference

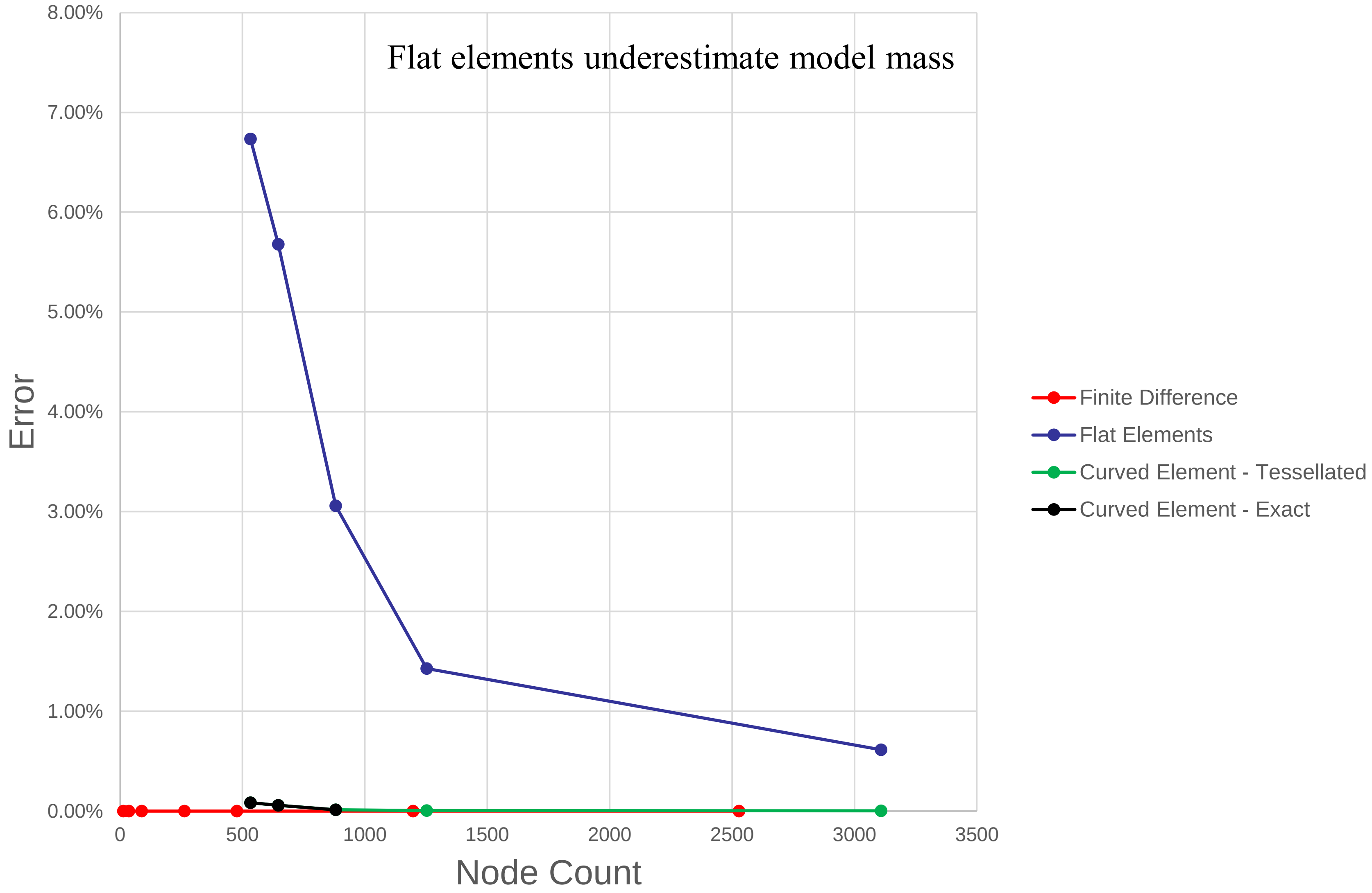


Flat Elements

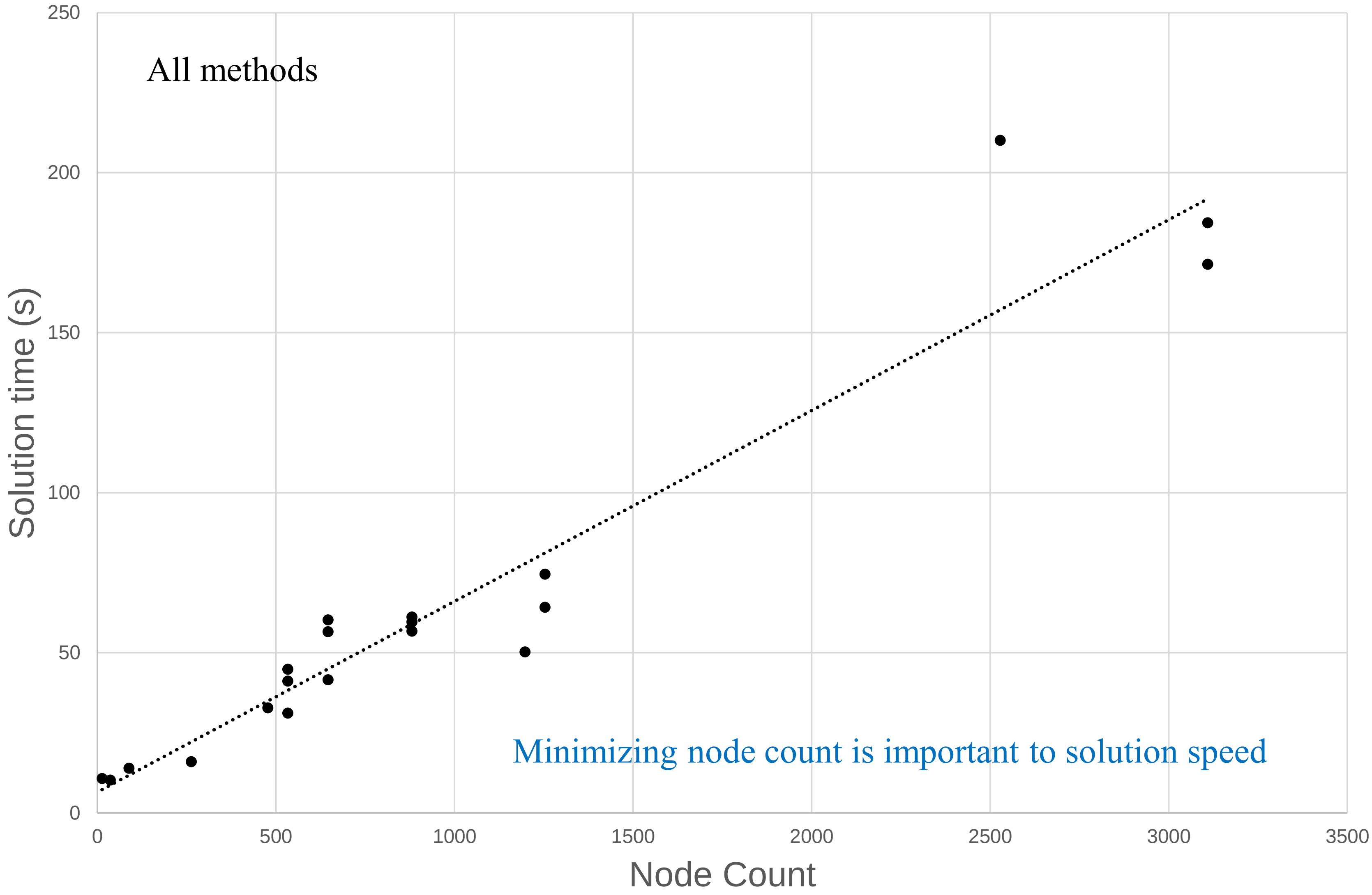


Curved Elements

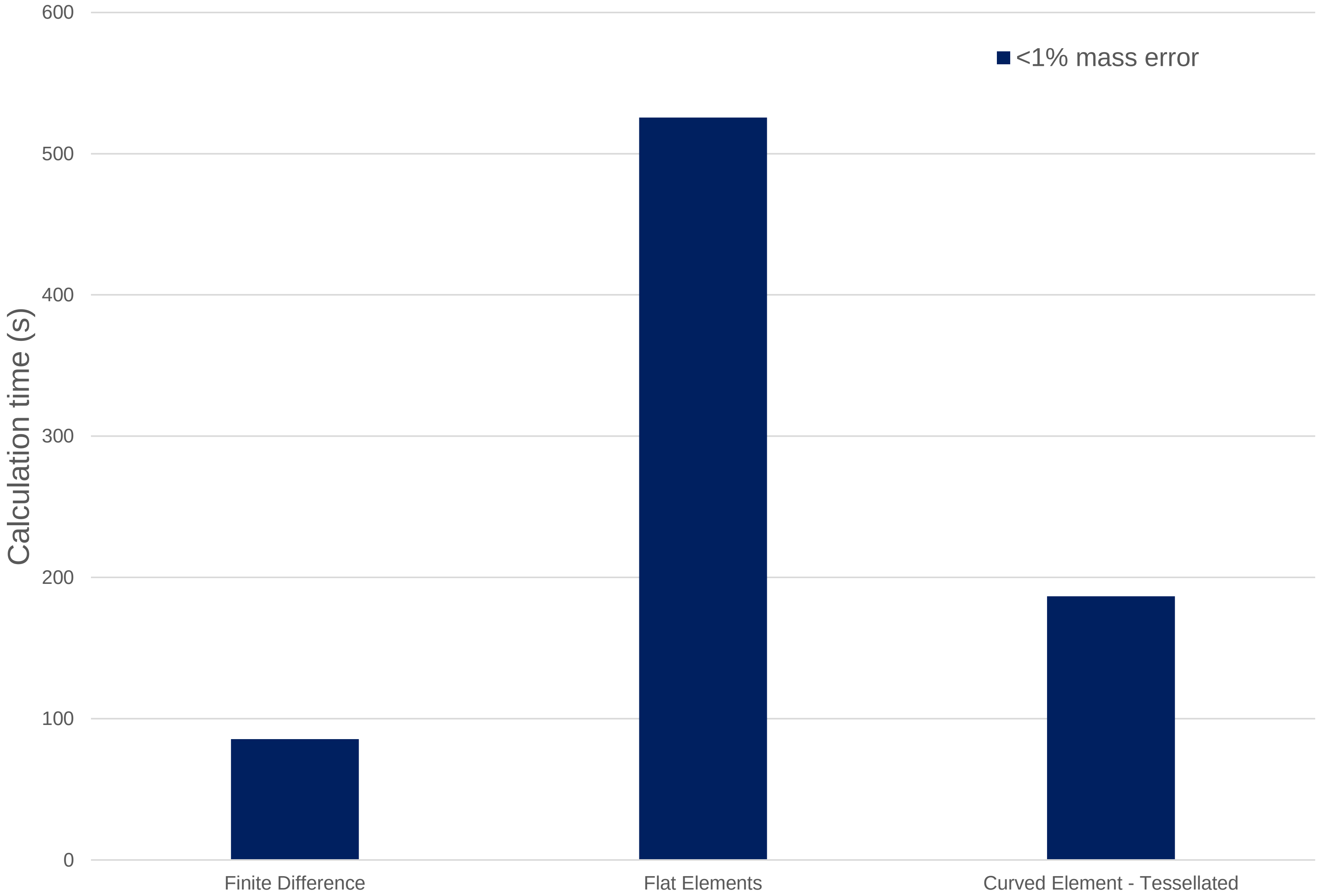
Reaction Wheel Mass Accuracy



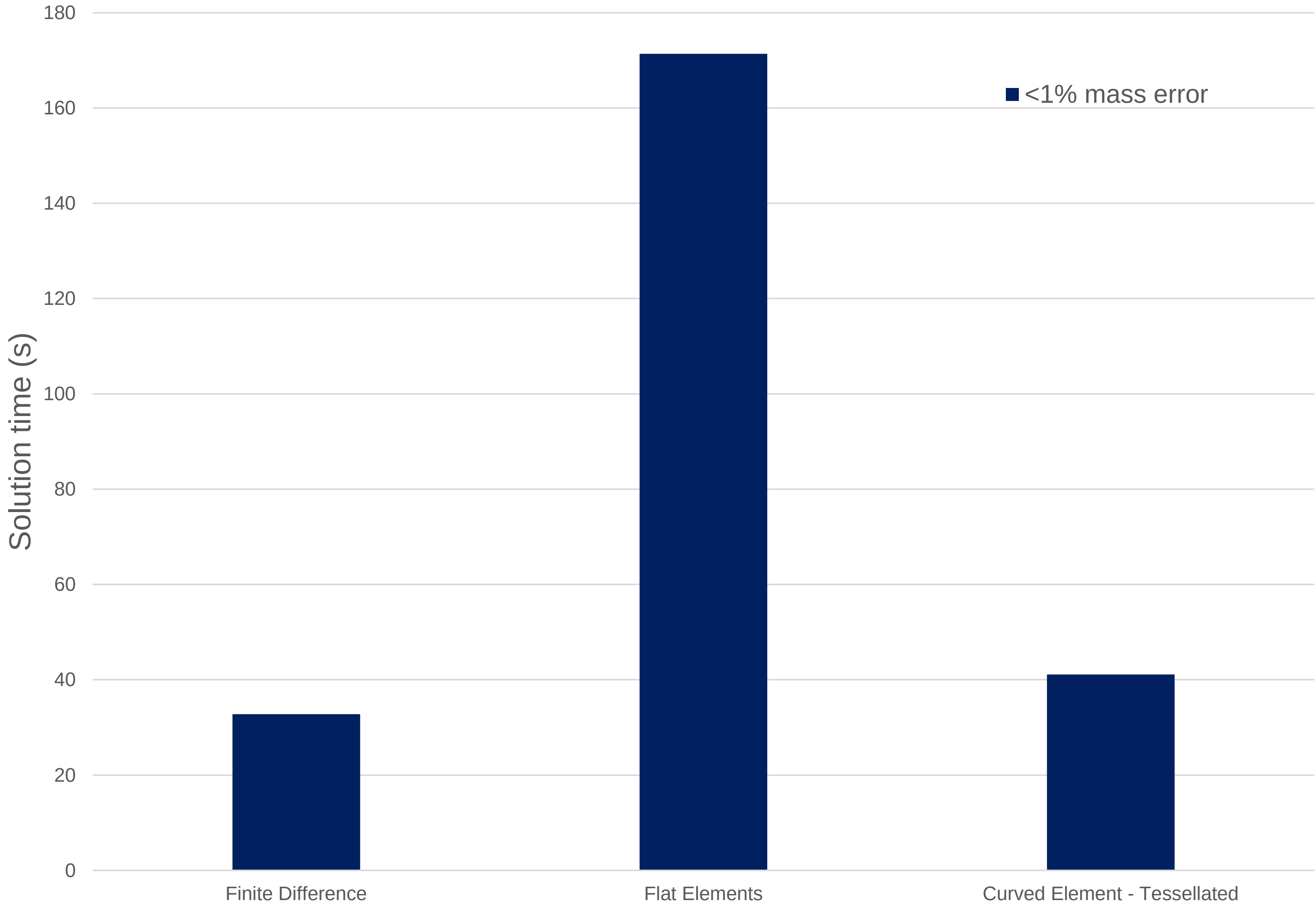
Reaction Wheel Solution Time vs Node Count



Reaction Wheel Radk Calculation Time



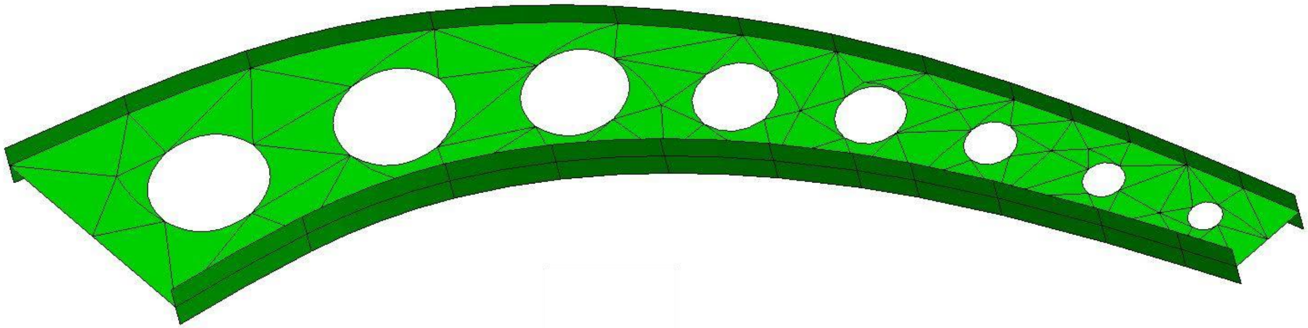
Reaction Wheel Solution Time

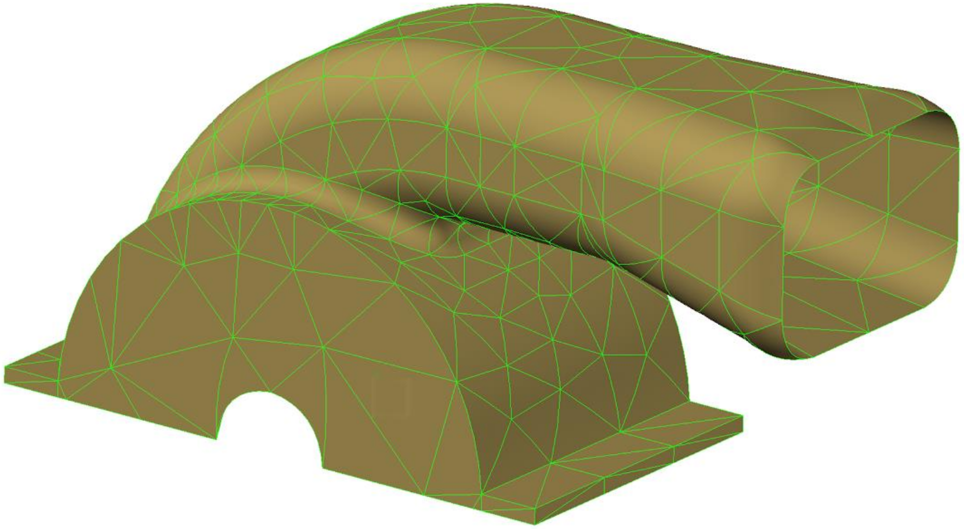


Reaction Wheel Discussion

- Geometry accuracy
  - Finite difference and curved elements provide accurate mass and surface area at all model sizes
  - Flat elements require more nodes for mass and surface area accuracy
- Calculation time
  - Flat element model must be increased in size to improve mass accuracy
    - Decreases efficiency of the model
  - Solution times are dependent on node count
    - Solutions may be repeated many times
    - Smaller models are better
  - The exact method for curved elements is not shown
    - It is computationally more expensive but only needed for special situations (discussed later)
- Conclusion
  - Finite difference and curved elements are the better options
    - Curved elements allow arbitrary geometry

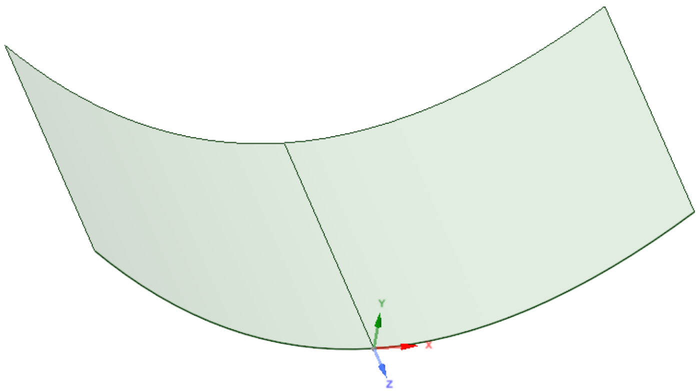
Geometries Benefitting from Curved Elements

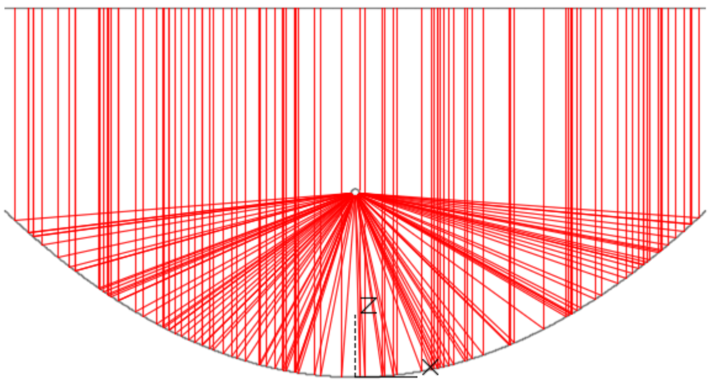




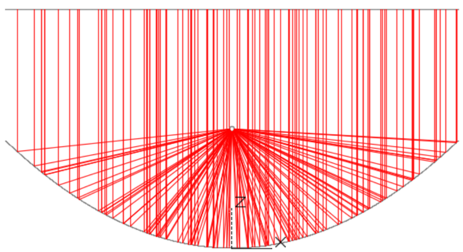
Precision Radiation Model

- Parabolic trough
  - Source surface emitting parallel rays
  - Black-body collector tube at trough focus
  - 1 million rays from source
- Reflection must be precise
  - All radiation should be absorbed by collector
    - Bij_{space} represents poor reflection of rays
    - Special case that requires precise reflections

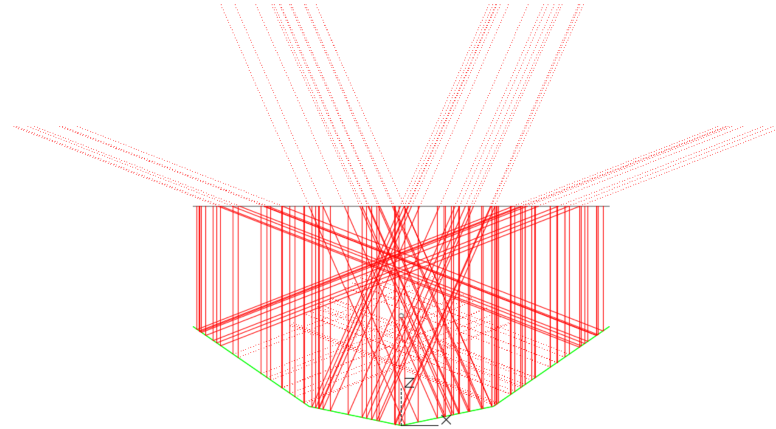




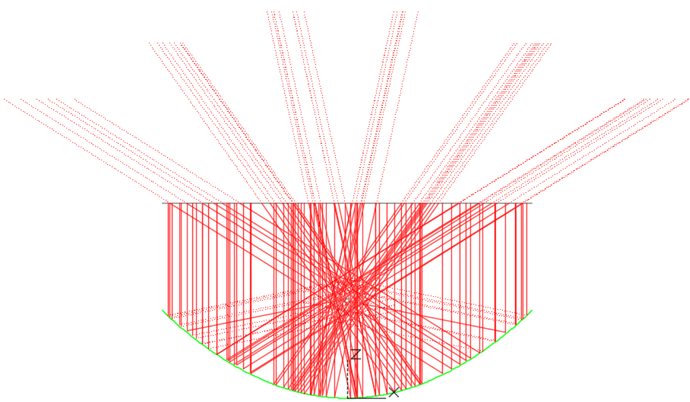
Parabolic Trough with 10 Nodes



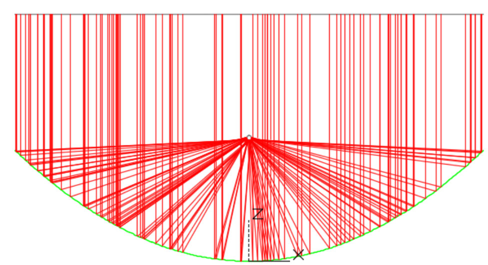
Finite Difference



Flat Elements



Curved Element -
Tessellated



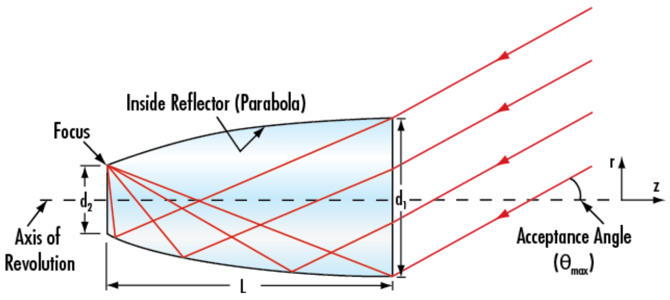
Curved Elements -
Exact

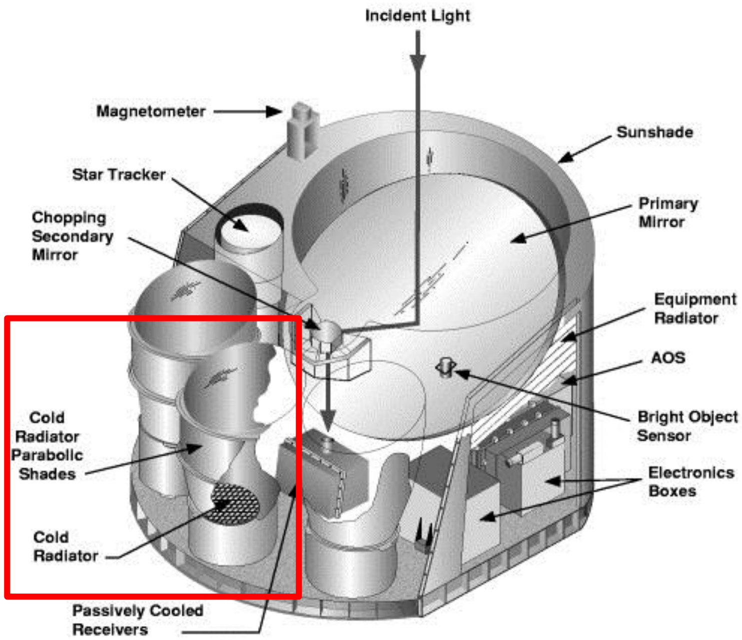
Precision Radiation Model Discussion

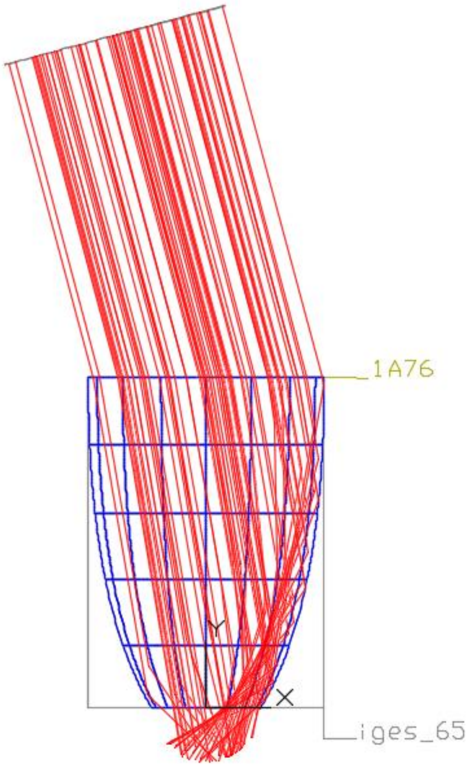
- Curved elements with exact radiation and finite difference are intrinsically accurate regardless of model size
- Flat elements and tessellated curved elements *can* get the correct answer, however…
  - Flat elements require more nodes
  - Tessellated curved elements require more nodes and/or tessellations
  - Trial and error required to find the model that gives the “correct” answer
    - Multiple runs for trial and error increase the cost
    - Not all models have a predetermined answer: what is “correct”?
  - Increased node count will increase solution time
- Not all geometries can be represented by finite difference objects

Compound Paraboloid

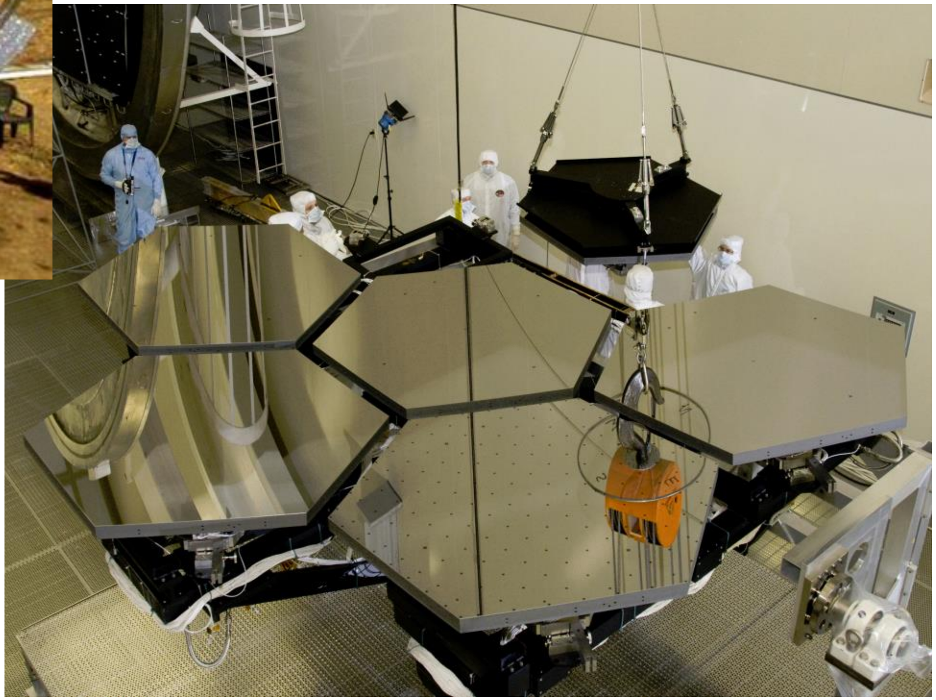
- Otherwise known as Winston cone
  - Radiator enhancer and shade
  - Solar concentrator
- Accurate representation requires curved elements or *many* flat elements







Odd-shaped Mirrors



Discretization Method Comparison

Method	Strengths	Weaknesses
Finite Difference	• Extremely low node count possible • Accurate geometry • Precise radiation with few nodes • Fast radiation calculations	• Limited shapes
Finite Element	• Arbitrary shapes	• Requires many nodes to represent curvature
Curved Element • Tessellated radiation	• Arbitrary shapes • Accurate geometry • Fast radiation calculations	• Requires many nodes count or tessellations for precise reflections from curved surfaces
Curved Element • Exact radiation	• Arbitrary shapes • Accurate geometry • Precise radiation calculations with few nodes	• Slower radiation calculations

Conclusions

- Use finite difference objects
  - For system-level models when geometry can be represented with provided geometric primitives
  - Early in design process when CAD geometry or access to a direct modeler (such as SpaceClaim) is not available
- Use curved elements
  - For system-level models with arbitrary geometry
  - Early in the design process along with a direct modeler for concept designs
  - With tessellation option when precise radiation is not required
  - With exact option for optics or concentrators
- Use flat finite elements
  - For arbitrary geometry
    - Without curvature
    - When high node count is required for temperature gradients